The Biology, Ecology and Pathology of *Phellinus noxius* in Taiwan 7

T.T. Chang

Division of Forest Protection, Taiwan Forestry Research Institute, 53 Nan-hai Road, Taipei 100, Taiwan

Introduction

Phellinus noxius (Corner) Cunn. is widely distributed in tropical regions in South-east Asia, Oceania and Africa (Larsen and Cobb-Poulle, 1990), where it causes a brown root disease that is responsible for the decline of numerous orchard and forest tree species (Singh *et al.*, 1980; Turner, 1981; Bolland, 1984; Hodges and Tenorio, 1984; Neil, 1986; Nandris *et al.*, 1987). In Taiwan in the 1950s, tea, coffee and 15 other plant species were documented as hosts of *P. noxius* based on the presence of a dark brown mycelial mat on the surface of diseased roots (Tsai, 1991). However, the causal fungus was not isolated and further studies of brown root disease were discontinued until the late 1980s because *P. noxius* basidiomes were rarely observed on host plants in the field. More recently, it has been isolated from woody hosts and its basidiomes have been produced on sawdust medium (Ann and Ko, 1992; Chang, 1992), thus confirming an association between the fungus and brown root disease on woody plants. Consequently, there has been a renaissance of studies on *P. noxius* and brown root disease during the last decade.

Phellinus noxius in Laboratory Culture

Well-developed basidiomes were rarely observed on diseased trees in the field, so the characteristics of pure cultures and laboratory-produced basidiomes were used for identification of *P. noxius*.

© CAB *International* 2002. *Tropical Mycology*, Vol. 1, *Macromycetes* (eds R. Watling, J.C. Frankland, A.M. Ainsworth, S. Isaac and C.H. Robinson)

The fungus was easily isolated from diseased roots and stems by using a selective medium consisting of malt extract (20 g), agar (20 g), benomyl (10 mg), dicloran (10 mg), ampicillin (100 mg) and gallic acid (500 mg) l^{-1} (Chang, 1995a). Cultures were initially whitish on malt extract agar and potato dextrose agar (PDA) becoming brown with irregular dark brown zone lines or patches permeating the culture. Arthroconidia and trichocysts were always present in the culture, while clamp connections were absent on generative hyphae. The arthroconidia were hyaline and rod-shaped and trichocysts were dark brown. The only specialized elements were yellow to rust-brown skeletal hyphae. Within the genus *Phellinus*, the combination of arthroconidia and trichocysts is only observed in cultures of *P. noxius* and is therefore very useful in the identification process. Examination of the fungus from diseased plants revealed that trichocysts were commonly present on the diseased tissues, but arthroconidia were rare or not observed.

Cultures isolated from 15 hosts showed similar growth responses to different temperature regimes, with an optimum temperature near 30°C, a maximum temperature above 36°C, and a minimum temperature of 10–12°C. However, the growth rates of different isolates at the optimum growth temperature varied greatly. The linear growth rates ranged from 3.4 to 0.8 cm day^{-1} (Chang, 1992; Ann *et al.*, 1999a). Mycelia of the tested isolates grew in PD broth with original pH values ranging from 3.5 to 7.0, but no growth was observed above pH 7.5 (Ann *et al.*, 1999a).

Tests for extracellular oxidases were positive for laccase and peroxidase but not for tyrosinase, indicating that *P. noxius* belongs to the group of white rot fungi (Chang, 1992). Chang *et al.* (1994) found that *P. noxius* did not secrete nitrate reductase and thus was unable to use $NaNO_3$, KNO_3 and $Ca(NO_3)_2$ as nitrogen sources. However, this species used ammonium salts such as NH_4NO_3, NH_4Cl, $(NH_4)_2HPO_4$ and $(NH_4)_2SO_4$, and organic nitrogen such as asparagine and urea.

Basidiome formation and morphology

In the field, basidiomes of *P. noxius* have been observed on only nine out of 101 host plant species, namely *Annona squamosa* L., *Casuarina equisetifolia* L., *Cinnamomum camphora* (L.) Nees et Eberm., *Delonix regia* (Boj.) Raf., *Euphoria longan* Lam., *Ficus elastica* Roxb., *Ficus microcarpa* L., *Litchi chinensis* Sonn. and *Melicope merrilli* (Kaneh. et Sasak. ex Kaneh.) Liu et Liao (Chang and Yang, 1998; Ann *et al.*, 1999b). However, isolates from all hosts produced basidiomes on a hardwood sawdust medium consisting of sawdust (40 kg), rice bran (10 kg), sucrose (50 g), NH_4NO_3 (10 g), citric acid (5 g) and about 15% (w/w) water in plastic bags (Chang and Yang, 1998). Basidiomes of *P. noxius* produced on sawdust medium were usually resupinate, whereas those observed in the field were resupinate to effused–reflexed. Although the macromorphology of *P. nox-*

ius varied between cultured and naturally occurring basidiomes, the micromorphology was similar. The hyphal system was dimitic comprising generative and skeletal hyphae. Generative hyphae were 2–4 μm in diameter, hyaline to yellow and lacked clamp connections. Skeletal hyphae were yellow-brown to bay with a diameter of 3–6 μm. Contextual and tramal setal hyphae were dark ferruginous and 370–602 × < 13 μm. Projection of the latter into the hymenium was difficult to observe. Basidiospores were smooth, hyaline, broadly ellipsoid to subglobose, and measured 3–4 × 4–7 μm.

Phellinus noxius in the Field

Disease pattern and dissemination

In recent years, the brown root disease caused by *P. noxius* has become one of the most serious problems of fruit and forest trees at lower elevations in central and southern Taiwan (Ann and Ko, 1992; Chang, 1992, 1995b). Several slowly expanding, circular disease patches extending from infection centres were observed in the field indicating spread from diseased to healthy trees by root contact. New disease patches were not commonly observed in the field indicating that airborne basidiospores and arthroconidia are not efficient in the establishment of new infections at their natural levels of production. Nevertheless, airborne basidiospores can initiate infections on freshly cut stumps or infest logging debris with subsequent spread to live trees by root contact (Anonymous, 1974a,b; Singh *et al.*, 1980; Turner, 1981; Hodges and Tenorio, 1984).

The survival of *Phellinus noxius*

The mycelium, including that within colonized wood, arthroconidia and basidiospores, was measured in soils with different matrix potentials (Chang, 1996). Survival of arthroconidia declined more slowly in soils with matrix potentials of –0.50 and –0.42 MPa than in soils with potentials of –0.15 and –0.025 MPa. However, arthroconidia were rarely recovered from the treatments after 3 months (Fig. 7.1). Basidiospores were not recovered after 3.5, 4, 4.5 and 5 months in the –0.025, –0.15, –0.42 and –0.50 MPa soil matrix potential treatments, respectively (Fig. 7.2). Mycelia which had colonized cellophane membranes buried in soil with potentials of –0.025 MPa were not recovered after 6 weeks, whereas mycelia on cellophane in soils of –0.50, –0.42 and –0.15 MPa were not recovered after 12 weeks (Fig. 7.3). *P. noxius* was not recovered from inoculated pieces of wood subjected to 1 month of flooding. However, in treatments with lower soil moisture, *P. noxius* survival ranged from 80 to > 90% over 2 years (Fig. 7.4). Colonies of *P. noxius* were not

recovered from the rhizosphere of soils around the colonized roots of three host species: *Calophyllum inophyllum* L., *C. equisetifolia*, and *C. camphora*. However, *P. noxius* was recovered from naturally colonized roots of these hosts 1–10 years after they were killed. These results indicate that woody debris in soils harbouring *P. noxius* plays an important role in the long-term survival of the fungus.

Although the longest recorded survival time of *P. noxius* in dead roots was 10 years after the host plant was killed, it appeared that the fungus could survive longer based on approximately 50% survival over 10 years (Chang, 1996). The survival pattern of *P. noxius* on different hosts over a long period of time might show differences, but only 10-year-old dead trees were available in the study. It was difficult to find roots that had been dead for longer periods because

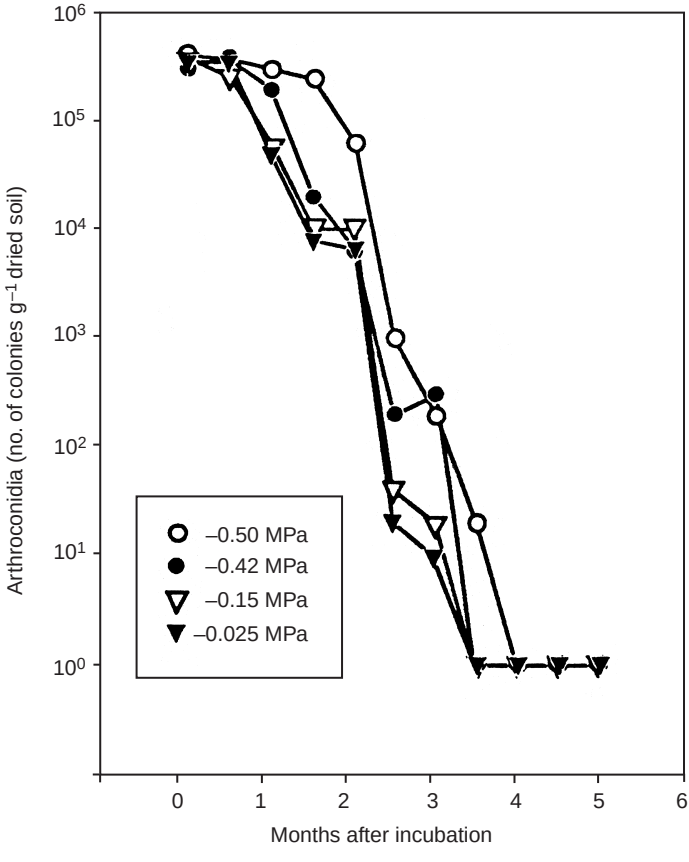

Fig. 7.1. Survival of *P. noxius* arthroconidia mixed in soils with varying soil moisture treatments at different incubation times. Each point is the mean of six replicates.

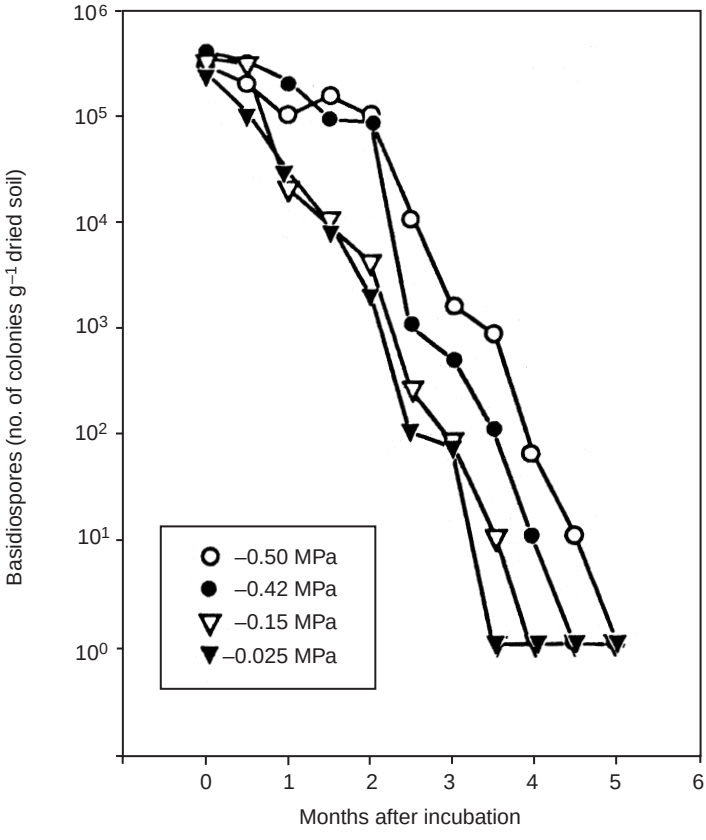

Fig. 7.2. Survival of *P. noxius* basidiospores mixed in soils with varying soil moisture treatments at different incubation times.

the disease has not been studied carefully until recently. After the death of its host, *Phellinus weirii*, which causes laminated root rot of *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) in the western United States and Canada, continues to live saprobically in the lower portion of the trunk and the root system for 50 years or more (Thies, 1984). The possibility that chlamydospores may play a role in the long-term survival of *P. noxius* was investigated. Previous work did not reveal chlamydospores in pure cultures of *P. noxius* (Anonymous, 1974b) and microscopic examination of colonized soils similarly did not reveal their presence (Chang, 1996). Based on these results, it was concluded that *P. noxius* does not form chlamydospores as a long-term survival strategy. However, *P. noxius* was able to live in woody debris in soil until the wood had rotted away.

Viability of basidiospores, arthroconidia and mycelia declined rapidly in soil compared with that of the fungus in colonized woody debris. Indeed, only the latter harboured the fungus in a viable state after 5 months. It was possible that

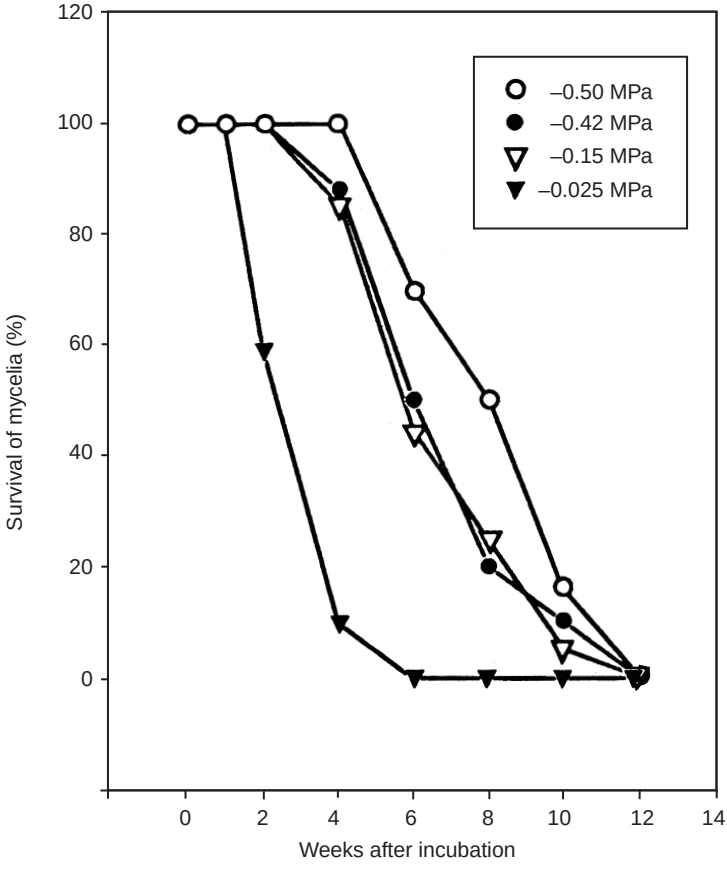

Fig. 7.3. Survival of *P. noxius* mycelia on cellophane buried in soils varying with soil moisture treatments at different incubation times.

populations of basidiospores and arthroconidia of low viability existed in soils after 5 months although they were not recoverable by the methods used in the study. Basidiospores are not generally regarded in a long-term survival context, but they play an important role in the long distance dissemination of *P. noxius*. Infection of trees, presumably by airborne basidiospores, has been reported for cacao and rubber (Anonymous, 1974b).

Submerging wood in water has been used to prevent postharvest colonization by wood-decaying fungi. In this study, when *P. noxius*-colonized wood sections were submerged in water, the fungus died within 1 month. This might have involved the activities of anaerobic microorganisms, but further study is required to determine the exact mechanism. Flooding colonized fields for more than 1 month might eliminate the inoculum source in colonized wood and roots. However, field studies are required to test this hypothesis and may lead to

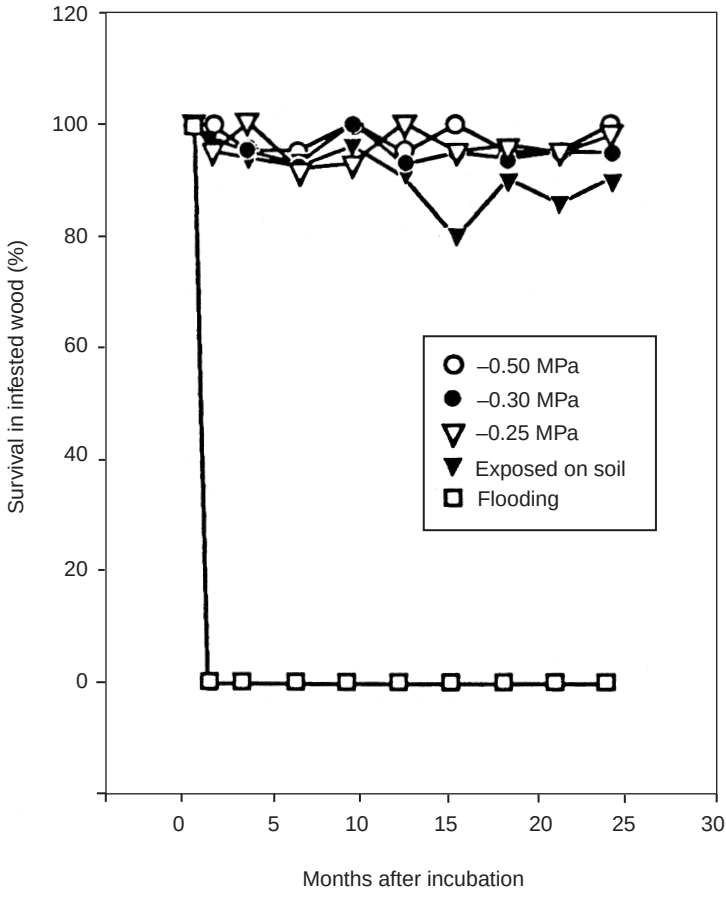

Fig. 7.4. Survival of *P. noxius* in artificially infected wood sections buried in soils with varying moisture treatments at different incubation times. Each point is the mean of six replicates. The least significant difference test among all treatments at different incubation times when the flooding treatment was excluded showed that the means at only three incubation times were significantly different ($P = 0.01$) from other treatments.

more effective field control practices. According to a disease survey, *P. noxius* occurred more frequently in fields with sandy soils, probably due to the better drainage and reduced likelihood of flooding even during high rainfall. Clay soils drain poorly and therefore these soils are more likely to be submerged, a situation that is detrimental to the survival of *P. noxius*.

Distribution and environment

P. noxius has been collected at 260 different sites in Taiwan, and two different sites on Chinmen Island, which is much closer to Fujian Province, China, than

to Taiwan. Collections were mostly from host plants growing in the low elevation plains and hills of western, eastern and southern Taiwan, while it was found on only a few hosts in northern Taiwan and was absent from the high mountainous areas. Of the 262 localities, 240 were from the plains with elevations < 500 m, while 22 localities were from low mountainous areas of 500–1000 m elevation (Chang and Yang, 1998; Ann *et al.*, 1999b).

P. noxius was observed mostly in central and southern Taiwan, in low elevation areas, indicating that the disease is primarily tropical and subtropical in distribution. This agrees with the results of previous studies (Hodges and Tenorio, 1984; Neil, 1986; Nandris *et al.*, 1987; Ann and Ko, 1992; Chang, 1992, 1995a). Only a few cases of the fungus disease were present in northern Taiwan. This could be as a result of rainfall distribution rather than temperature because the lowest and highest temperatures in central and northern Taiwan do not differ. The fungus was also found on Chinmen Island where the temperature is lower than in northern Taiwan. However, the winter monsoon brings long periods of rain and high humidity to northern Taiwan, while the other regions are usually dry.

Soil samples (153) collected from the rhizospheres of the diseased plants were used for determination of soil pH and texture. Although *P. noxius* did not favour a particular soil pH, it was not found in extreme pH conditions. It was found in soils with pH 4–9, and most frequently in soils with pH 5–8. Diseased plants were not found in soils < pH 4 or > pH 9. *P. noxius* occurred mostly in soils classified as sand, loamy sand and sandy loam, although it was occasionally found in other types of soils.

This study also demonstrated that soil pH has no significant effect on *P. noxius* and the effect of pH may be expressed through the host rather than directly on the fungus. This phenomenon has also been shown by *Armillaria mellea* (Vahl: Fr.) Kummer and *P. weirii* (Murr.) Gilbn., two important root rot fungi in temperate forests (Angwin, 1985; Shaw and Kile, 1991). Soil pH appears to have no significant effect on *P. noxius* in Taiwan, but the fungus is more common in sandy soils. The latter may be a feature of drainage: sandy soils are generally well drained and other evidence suggests that dry soil conditions are favourable to the survival of *P. noxius* (Chang, 1996). Moreover, the percentage of trees infected by *Armillaria ostoyae* (Romagnesi) Herink in Ontario, Canada, was higher at a dry site than at a wet site (Whitney, 1988). Additionally, the disease caused by *Heterobasidion annosum* (Fr.) Bref. was found to occur more frequently in drier sites with sandy soil (Rishbeth, 1950).

Symptoms and host ranges

The disease symptoms caused by *P. noxius* progressed from discoloration of leaves to gradual defoliation, slow growth and eventual death of the infected trees. A dark brown mycelial mat formed on the surface of the roots and up the

base of the stem but usually no further than 1 m above the ground. Masses of sand and stone usually adhered to the mycelium on the root and stem surface. Dead colonized bark was brittle and easily removed, and its inner surface was covered with white to brownish mycelial mats with a network of mycelial cords. The colonized woody tissues eventually decomposed and showed typical white rot symptoms. The diseased trees also died when the infection reached the root crown.

P. noxius was identified from 101 woody plants, comprising 91 hardwoods and 10 conifers, and four annual herbaceous plants. The four annuals were found in a Taichung harbour windbreak of *C. equisetifolia* which was heavily infected with *P. noxius*. In this case, the fungus caused brown root rot but did not severely wilt the foliage (Chang and Yang, 1998; Ann *et al.*, 1999b).

In order to determine the variation in host susceptibility and virulence of isolates from various hosts, 12 tree species were inoculated in all possible combinations with an isolate from each of the hosts (Chang, 1995b). All isolates of *P. noxius* used were able to cause disease in all 12 tree species. However, disease incidence was quite variable, ranging from 20 to 90% of the trees. Survival of *Acacia confusa* Merr. and *Salix babylonica* L. was significantly better than that of other host plants using logistic regression analysis. Indeed the incidence of disease was significantly lower on these two tree species, indicating that they may have some level of resistance or tolerance to the disease. In contrast, there were no significant differences among fungal isolates. Cross pathogenicity tests demonstrated that *P. noxius* had a wide host range without showing host specificity for any of the species tested. However, different degrees of resistance to the fungus might be present in different tree species. As has been observed in the field, some trees such as *Melaleuca leucadendra* (L.) L. and *Alstonia scholaris* R. Br. were found to be free of disease when they were growing in close proximity to diseased trees of other species. Hence, further study is required to determine whether resistant tree species exist.

Fungicidal Effect of Urea on *P. noxius* in Alkaline Soil

Removal of colonized stumps and roots from the soil to reduce the source of inoculum has been widely used to control diseases caused by root rot fungi (Kuhlman *et al.*, 1976; Wallis, 1976; Thies *et al.*, 1994). This practice is probably more effective for *P. noxius* than for other root rot fungi because *P. noxius* rarely produces basidiospores in the natural environment (Chang, 1995b). However, small roots are easily broken off and left in the soil during uprooting. These infected pieces usually act as primary inocula and spread the disease. Thus, control practices that reduce or eradicate *P. noxius* from colonized root residue are essential for effective control of the disease. Urea proved to be effective at killing *P. noxius* in colonized wood fragments (Chang and Chang, 1999). *P. noxius* was not recovered from pieces of inoculated wood placed in or on soil

amended with urea, $(NH_4)_2CO_3$ or aqueous ammonia. High concentrations of volatile NH_3 were detected in these treatments, indicating that NH_3 generated from these chemicals was fungicidal to *P. noxius* (Table 7.1). A high concentration of volatile NH_3 was detected from non-autoclaved soil amended with urea but not from amended, autoclaved soil, indicating that soil microorganisms were involved in NH_3 generation. To kill *P. noxius* completely required 3000 p.p.m. urea in soil. Volatile NH_3 was generated from urea in alkaline soil but not in acidic soil (Table 7.2). Similar quantities of volatile NH_3 were generated at temperatures ranging from 12 to 32°C. A large quantity of NH_3 was generated at low soil matrix potentials (−0.75 to −0.15 MPa), while high potentials (> −0.025 MPa) and flooded soil hindered production of volatile NH_3 (Table 7.3). Ammonia was more effective at killing *P. noxius* growing in smaller pieces of wood than in larger pieces. The fungus was not recovered from wood pieces less than 3 cm in diameter. Volatile NH_3 was also lethal to six other root rotting fungi: *Ganoderma australe* (Fr.) Pat., *Ganoderma lucidum* (Curt.:Fr.) Karst., *Ganoderma tropicum* (Jungh) Bres., *Rigidoporus vinctus* (Berk.) Ryv., *Heterobasidion annosum* and *Rosellinia necatrix* Prill.

This wide spectrum of fungicidal activity is similar to that of soil fumigants and could be enhanced by covering the ground with plastic sheeting. Urea is an inexpensive fertilizer and has relatively low toxicity to plants, especially to perennial woody plants. Thus, urea holds promise as an agent for controlling *P. noxius* and other fungi that cause disease of woody plants.

Table 7.1. Effects of urea and other chemicals on volatile NH_3 generation and *P. noxius* survival in inoculated wood sections buried in soil.

		Survival of *Phellinus noxius* (%)		Concentration of
	p.p.m.	In soil	On soil	NH_4^+ (mg l^{-1})
Urea				
Autoclaved soil	0	100[a2]	100[a]	5.3[b]
	1000	100[a]	100[a]	6.4[b]
Non-autoclaved soil	0	100[a]	100[a]	8.5[b]
	1000	100[a]	100[a]	87.4[b]
	3000	0[b]	0[b]	1320[a]
KNO_3	3000	100[a]	100[a]	3.2[b]
NH_4NO_3	3000	100[a]	100[a]	8.5[b]
$(NH_4)_2SO_4$	3000	100[a]	100[a]	132[b]
$(NH_4)_2CO_3$	3000	0[b]	0[b]	158[a]
Ammonia water	400	0[b]	0[b]	1325[a]
Control[3]	100[a]	100[a]	3.5[b]	

[1]Concentration of NH_4^+ (mg l^{-1}) was analysed by ion exchange chromatography.
[2]In each column values followed by the same letter are not significantly different according to the least significant difference test (P = 0.05). Each value is the mean of ten and six replicates for survival and concentration, respectively.
[3]Soil without chemicals was used as a control.

Table 7.2. Effects of soil type on generation of volatile NH_3 from urea and *P. noxius* survival in inoculated wood sections buried in the soil.

Soil source	pH	Survival of *P. noxius* (%)	Concentration of NH_4^+ (mg l^{-1})[1]
YMS3	6.1	100[a2]	3.3[c]
TCS	7.3	0[b]	1128[a]
SCS	5.6	100[a]	126[b]
SSS	7.9	0[b]	1832[a]
HLS	7.2	0[b]	1650[a]
TMS	6.5	100[a]	187[b]
KSS	9.2	0[b]	1358[a]
CHS	5.2	100[a]	252[b]

[1]Concentration of NH_4^+ (mg l^{-1}) was analysed by ion exchange chromatography; 3000 p.p.m. urea was added.
[2]In each column values followed by the same letter are not significantly different according to the least significant difference test (P = 0.05). Each value is the mean of ten and six replicates for survival and concentration, respectively.
[3]YMS, Yan-ming-shan; TCS, Taichung Harbour area; SCS, Hsin-chu City; SSS, Commercial sand for construction; HLS, Hualien coast; TMS, Taimalee, Taitung County; KSS, Kaohsiung County; CHS, Hsin-chu City.

Conclusion

Based on the numbers and dates of papers published and cited in forestry abstracts on six common root and butt rot fungi, *H. annosum*, *Armillaria* spp., *P. weirii*, *Inonotus tomentosus* (Fr.) Teng, *Phaeolus schweinitzii* (Fr.) Pat. and *P. noxius*, research on *P. noxius* has been initiated in more recent years and has the fewest papers published on it (Stenlid, 1998). However, it is believed that the economic losses caused by *P. noxius* in warmer climates are not proportional to

Table 7.3. Effects of soil matrix potential on generation of NH_3 from urea and *P. noxius* survival in inoculated wood sections.

Soil matrix potential (MPa)	Survival of *P. noxius* (%)	Concentration of NH_4^+ (mg l^{-1})[1]
–0.75	0[b2]	1125[a]
–0.50	0[b]	1231[a]
–0.30	0[b]	1025[a]
–0.15	0[b]	1102[a]
–0.025	100[a]	4.8[b]
Flooding	100[a]	3.8[b]

[1]Concentration of NH_4^+ (mg l^{-1}) was analysed by exchange chromatography; 3000 p.p.m. urea was added.
[2]In each column values followed by the same letter are not significantly different according to the least significant difference test (P = 0.05). Each value is the mean of ten and six replicates for survival and concentration, respectively.

the number of papers published compared with the other five root and butt rot fungi. It is remarkable that there were no published papers on the disease control of *P. noxius* brown root disease. Hopefully, more scientists will begin to study the impact, control and management of *P. noxius* brown root disease in the near future.

References

Angwin, P.A. (1985) Environmental factors influencing the rate of spread of *Phellinus weirii* (Murr.) Gilbertson in young-growth Douglas-fir. MS Thesis, Oregon State University, Corvallis, Oregon.

Ann, P.J. and Ko, W.H. (1992) Decline of longan tree: association with brown root rot caused by *Phellinus noxius*. *Plant Pathology Bulletin* 1, 19–25.

Ann, P.J., Lee, H.L. and Huang, T.C. (1999a) Brown root rot of 10 species of fruit trees caused by *Phellinus noxius* in Taiwan. *Plant Disease* 83, 746–750.

Ann, P.J., Lee, H.L. and Tsai, J.N. (1999b) Survey of brown root disease of fruit and ornamental trees caused by *Phellinus noxius* in Taiwan. *Plant Pathology Bulletin* 8, 51–60.

Anonymous (1974a) Root diseases. Part I: Detection and recognition. *Rubber Research Institute Malaya Plant Bulletin* 133, 111–120.

Anonymous (1974b) Root diseases. Part II: Control. *Rubber Research Institute Malaya Plant Bulletin* 134, 157–164.

Bolland, L. (1984) *Phellinus noxius*: cause of a significant root rot in Queensland hoop pine plantation. *Australian Forestry* 47, 2–10.

Chang, T.T. (1992) Decline of some forest trees associated with brown root rot caused by *Phellinus noxius*. *Plant Pathology Bulletin* 1, 90–95.

Chang, T.T. (1995a) A selective medium for *Phellinus noxius*. *European Journal of Forest Pathology* 25, 185–190.

Chang, T.T. (1995b) Decline of nine tree species associated with brown root rot caused by *Phellinus noxius* in Taiwan. *Plant Disease* 79, 962–965.

Chang, T.T. (1996) Survival of *Phellinus noxius* in soil and in the roots of dead host plants. *Phytopathology* 86, 272–276.

Chang, T.T. and Chang, R.J. (1999) Generation of volatile ammonia from urea fungicidal to *Phellinus noxius* in infested wood in soil under controlled conditions. *Plant Pathology* 48, 337–344.

Chang, T.T. and Yang, W.W. (1998) *Phellinus noxius* in Taiwan: distribution, host plants and the pH and texture of the rhizosphere soils of infected hosts. *Mycological Research* 102, 1085–1088.

Chang, T.T., Chiu, W.H. and Young, W.W. (1994) Selective nitrogen assimilation by *Phellinus noxius* and related fungi. *Plant Pathology Bulletin* 3, 230–233 (in Chinese).

Hodges, C.S. and Tenorio, J.A. (1984) Root disease of *Delonix regia* and associated tree species in the Mariana Islands caused by *Phellinus noxius*. *Plant Disease* 68, 334–336.

Kuhlman, E.G., Hodges, C.S. Jr and Froelich, R.C. (1976) *Minimizing losses to* Fomes annosus *in the southern United States*. USDA Forest Service Paper SE-151. USDA Forest Service, Oregon.

Larsen, M.J. and Cobb-Poulle, L.A. (1990) *Phellinus* (*Hymenochaetaceae*) a survey of the world taxa. *Synopsis Fungorum* 3, 1–206.

Nandris, D., Nicole, M. and Geiger, J.P. (1987) Root rot diseases of rubber trees. *Plant Disease* 71, 298–306.

Neil, P.E. (1986) A preliminary note on *Phellinus noxius* root rot of *Cordia alliodora* plantings in Vanuatu. *European Journal of Forest Pathology* 16, 274–280.

Rishbeth, J. (1950) Observation on the biology of *Fomes annosus*, with particular reference to East Anglian pine plantations. I. The outbreaks of disease and ecological status of the fungus. *Annals of Botany* 55, 365.

Shaw, C.G. III and Kile, G.A. (1991) *Armillaria root disease*. Agriculture Handbook No. 691. USDA Forest Service, Washington, DC.

Singh, S., Bola, L. and Kumar, J. (1980) Diseases of plantation trees in Fiji Islands I, Brown root rot of mahogany (*Swietenia macrophylla* King). *Indian Forestry* 106, 526–532.

Stenlid, J. (1998) Opening remarks. In: Delatour, C., Guillaumin, J.J., Lung-Escarment, B. and Marcais, B. (eds) *Root and Butt Rot of Forest Trees*. INRA, Paris, pp. 13–17.

Thies, W.G. (1984) Laminated root rot. The quest for control. *Journal of Forestry* 82, 345–356.

Thies, W.G., Nelson, E.E. and Zabowski, D. (1994) Removal of stumps from a *Phellinus weirii* infested site and fertilization affect mortality and growth of planted Douglas-fir. *Canadian Journal of Forest Research* 24, 234–239.

Tsai, Y.P. (1991) *List of Plant Diseases in Taiwan*, 3rd edn. Plant Protection Society of the Republic of China & Plant Phytopathological Society of the Republic of China, Taichung, Taiwan.

Turner, P.D. (1981) *Oil Palm Diseases and Disorders*. Oxford University Press, Kuala Lumpur, Malaysia.

Wallis, G.W. (1976) Phellinus (Poria) weirii *root rot. Detection and management proposals in Douglas-Fir stands*. Canadian Forest Technical Report 12. Canadian Forestry Service, Victoria, BC.

Whitney, R.D. (1988) *The Hidden Enemy*. Canadian Forestry Service, Ontario, Canada.